TITLE OF THE INVENTION

SYSTEM AND METHOD FOR PREVENTING PISTON-VALVE COLLISION ON A NON-FREEWHEELING INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention generally relates to an electro-hydraulic device for actuating a control element of an internal combustion engine. More particularly, the present invention relates to a system and method for regulating a high-pressure hydraulic supply to electro-hydraulic engine valve actuators.

Description of the Background Art

[0002] The internal combustion engine is well known and has garnered much attention since its creation. Because of its ubiquitous use, substantial efforts are constantly made to improve designs for the internal combustion engine and for its control systems. Of the many advancements made, independent valve actuation and electronic fuel injection were conceived to improve performance and efficiency over cam-based engines.

[0003] With independent valve actuation systems, the engine valves can come in contact with the engine pistons. This valve – piston collision can cause serious engine damage leading to engine failure. Therefore, valve actuation systems are contemplated that prevent such valve–piston collisions from occurring.

[0004] Piston-valve collision has been of particular concern for electro-hydraulic valve-trains on non-freewheeling engines, such as heavy-duty diesel engines. The current solution for solving this problem relies heavily on feedback control based upon valve lift measurements, which is neither reliable nor cost effective. For example, U.S. Patent No. 6,092,495 describes a method of controlling electronically

controlled valves to prevent interference between the valves and a piston. While the system can prevent piston-valve collision, it is flawed because a failure in the electrical control system could cause severe engine damages.

[0005] Thus, there is a need for new and improved systems and methods for valve control in a combustion engine that provide reliable piston-valve clearance.

SUMMARY OF THE INVENTION

[0006] According to one aspect of the present invention, a system and method are provided for regulating high-pressure hydraulic supply to an electro-hydraulic valve actuator. The present invention provides reliable piston-valve clearance.

[0007] Another aspect of the present invention is generally characterized in a valve actuation system for use in an internal combustion engine comprising at least one combustion cylinder having a piston and an engine valve. The valve actuation system includes a hydraulic pump, a high-pressure reservoir, and an electro-hydraulic valve actuator. The hydraulic pump is configured to produce a hydraulic output based on a valve-piston clearance profile of the cylinder of the combustion engine. The high-pressure reservoir is coupled with the hydraulic pump. The electro-hydraulic valve actuator is coupled with the high-pressure reservoir and configured to actuate at least one engine valve of the combustion engine according to an output of the hydraulic pump.

[0008] The above and other features and advantages of the present invention will be further understood from the following description of the preferred embodiments thereof, taken in conjunction with the accompanying drawings wherein like reference numerals are used throughout the various views to designate like parts.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a schematic diagram showing an embodiment of an electro-hydraulic valve actuation system for a combustion engine according to the present invention.

[0010] FIG. 2 is a graph of the piston-valve clearance characteristics of a computer simulation of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] An embodiment of an internal combustion engine 100 having an electro-hydraulic valve actuation system according to the present invention is shown in FIG. 1. The engine 100 includes at least one piston-driven combustion cylinder (not shown) in communication with at least one engine control valve 106 (e.g., intake or exhaust valve), an electro-hydraulic actuator 102 for opening and closing valve 106, and a hydraulic pump 104. The hydraulic pump 104 may be a cam-driven pump and is fluidly connected to the electro-hydraulic valve actuator via a high-pressure reservoir 110.

[0012] In the embodiment shown in FIG. 1, hydraulic pump 104 includes a plunger 104b that is driven by a cam 104a. The geometry (i.e., shape) of the cam 104a can be selected to drive the plunger 104b as desired to charge the pressure of the fluid in the high-pressure reservoir 110. Preferably, the geometry of the cam is selected based on the piston-valve clearance curve for the combustion cylinder, such that when the engine piston is moving close to the valve 106, the high-pressure begins to drop; that is, the cam 104a starts to move away from the plunger 104b. For example, as shown in Fig. 1, cam 104a may have concave portions 104a-1 and 104a-2 corresponding to a crank angle of the engine when the engine piston moves close to the engine valve 106, thereby allowing plunger 104b to move toward cam 104a when piston-valve clearance becomes small.

[0013] Electro-hydraulic actuator 102 includes control valves 102a and 102b, which are preferably electric solenoid valves, check valves 102c and 102f, control chamber 102d, and a plunger 102e. Control valves 102a and 102b can be opened and shut to control the direction of plunger 102e to actuate the engine valve 106, and can be controlled electronically, such as via an electronic control unit (ECU) or processor (not shown). Control valve 102a (high-pressure control valve) allows high-pressure hydraulic fluid to travel into the control chamber 102d, to force the plunger 102e to travel away toward valve 106. Hydraulic fluid may be allowed to return to the high-pressure reservoir 110 via check valve 108 one-way only. Opening control valve 102b (low-pressure control valve) allows high-pressure fluid in the control chamber 102d to travel to low–pressure, which may be connected to a low-pressure hydraulic fluid supply, such as a regulated low-pressure reservoir (not shown). Check valve 102f allows hydraulic fluid to flow back to the control chamber 102d, should the pressure in control chamber 102d decrease below the pressure of the low pressure hydraulic fluid supply.

[0014] Check valve 102c allows fluid to flow from the control chamber 102d, one-way only, to the high-pressure reservoir 110, when the pressure in the control chamber 102d exceeds the pressure in the high-pressure reservoir 110. Thus, even when control valve 102b is closed, check valve 102c creates a feedback loop – as the cam 104b moves away from the plunger 104a, the pressure in the high-pressure reservoir 110 begins to drop below the pressure in the control chamber 102d, and check valve102c opens. Thus, piston-valve collision can be prevented reliably without reliance on electronic control systems.

[0015] A hydraulic accumulator 112 is in fluid connection to the high-pressure reservoir 110. The accumulator 112 is able to store excessive hydraulic fluid when

the high-pressure control valve 102a is closed and yet plunger 104a continues to pump fluid into reservoir 110. The piston 112a of the accumulator tends to respond to low-pressure fluctuation more than high frequency fluctuation. Here, the pressure drop due to the cam 104a shape design as the engine piston moves close to the valve 106 is high frequency. Therefore, the accumulator 112 is preferably slow to react to this fluctuation, which allows the pressure to fluctuate to a significant level such that the check valve 102c can open.

[0016] In operation, the cam-driven hydraulic pump 104 supplies high-pressure hydraulic fluid to the electro-hydraulic valve actuator 102. The cam 104a is preferably mechanically linked to the engine crankshaft (not shown) with a 2:1 ratio (i.e., the engine crankshaft rotates two revolutions while the cam 104a rotates one revolution). The cam profile is preferably shaped to correspond to the piston-valve clearance profile, so that as the engine piston moves toward the engine valves and the instantaneous piston-valve clearance becomes smaller, the pump plunger 104b moves toward the cam 104a. As the plunger 104b moves toward the cam 104a, the hydraulic pressure in high-pressure reservoir 110 drops. As a result, check valve 102c opens and high-pressure hydraulic fluid travels from control chamber 102d to reservoir 110, which allows the engine valve 106 to move away from the engine piston to avoid piston-valve collision even when control valve 102b is still closed. Control valves 102b is opened to allow hydraulic fluid to return to the low-pressure region. Control valves 102a and 102b are closed, and as the engine piston moves away from top-dead center position, the hydraulic pressure in the high-pressure reservoir 110 is built back up. Control valve 102a is then opened to cycle engine valve 106 for the next combustion event.

[0017] Referring now to FIG. 2, we assume that the low-pressure control valve 102b has failed to open before the top dead center to avoid piston-valve collision. FIG. 2 shows a simulation of valve clearance and valve lift, versus timing of the cylinder. The top graph shows the control signal for the high-pressure control valve 102a, the middle graph shows the control signal for the low-pressure control valve 102b, and the bottom graph shows valve lift and clearance (piston-valve clearance profile). The bottom axis of each graph is the crank angle of the engine, which corresponds to the position of the piston.

[0018] In operation, high-pressure control valve 102a is initially closed to allow high-pressure to build up in reservoir 110. High-pressure control valve 102a is opened, which causes plunger 102e to actuate valve 106 to open. The initial valve lift is shown as approximately 12 mm and settles quickly at about 10 mm. As the engine piston approaches the valve 106, the valve 106 begins to close (i.e., valve lift decreases). One can see that the piston-valve clearance becomes small as the piston approaches top-dead-center, but piston-valve collision is avoided even before the low-pressure control valve 102b is opened.

[0019] As a result of the novel mechanical design of the present invention, piston-valve collision can be prevented even if there is a failure in the electronic control system.

[0020] While the invention has been described in detail above, the invention is not intended to be limited to the specific embodiments as described. It is evident that those skilled in the art may now make numerous uses and modifications of and departures from the specific embodiments described herein without departing from the inventive concept.

[0021] It will be appreciated that the present invention can be implemented in a number of types of internal combustion engines. The engine can have any number of cylinders.